

MODEL SSP-3

SOLID-STATE STELLAR PHOTOMETER

TECHNICAL MANUAL FOR

THEORY OF OPERATION AND OPERATING PROCEDURES

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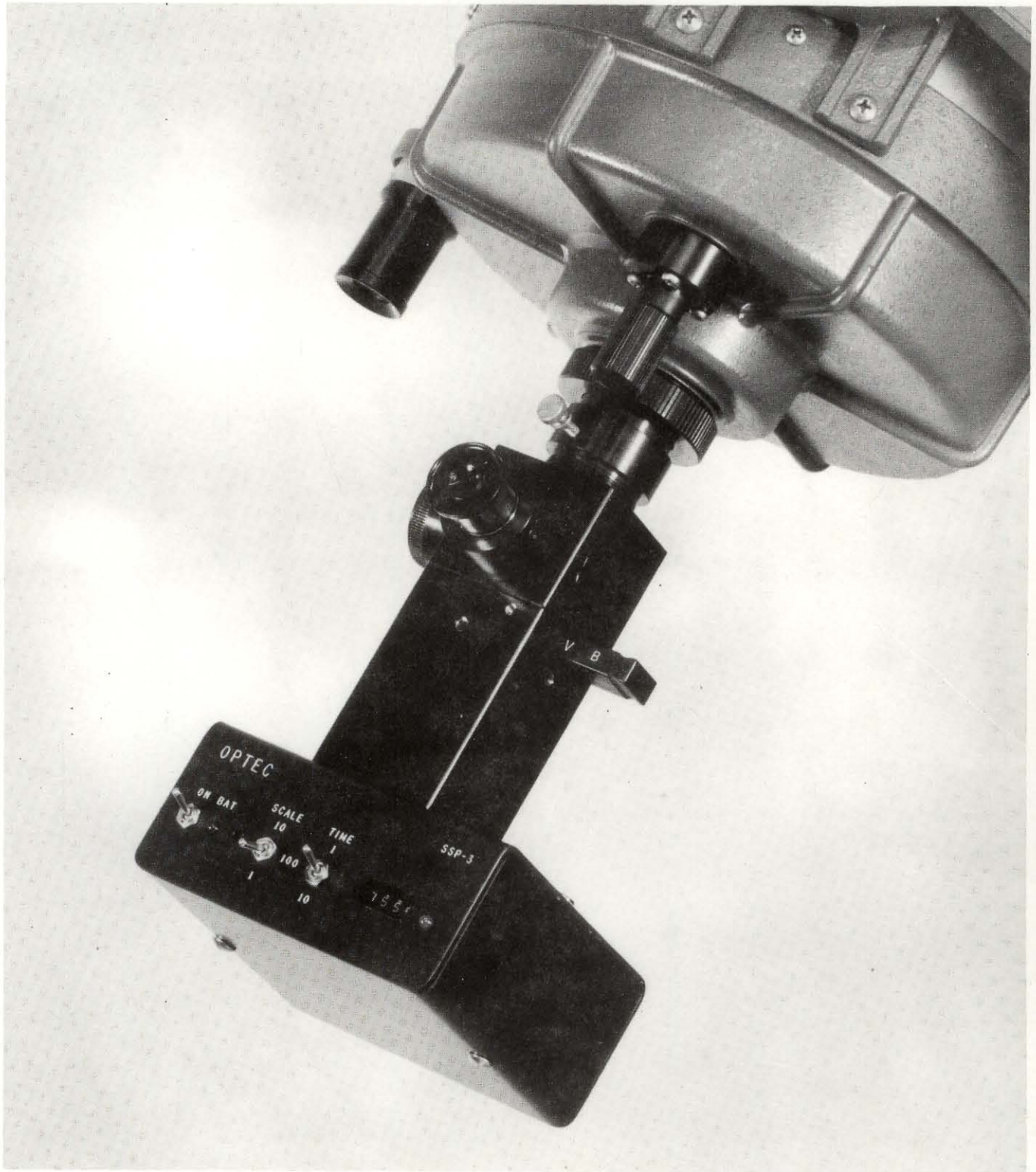


Figure 1-1. SSP-3 Solid-State Photometer shown with Celestron C-8 Telescope.

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SECTION 1.0

INTRODUCTION

By using an ultra-sensitive solid-state detector and integrated digital electronics, Optec has designed a unique stellar photometer enclosed in a single small package. All the electronics including detector, electrometer amplifier, voltage-to-frequency conversion electronics, and digital display are contained in one easy-to-handle unit and powered by a rechargeable 9-volt NiCd battery. The model SSP-3 Stellar Photometer makes the concept of a "portable observatory" a reality. All that is needed to make accurate and meaningful measurements of variable stars is a telescope, chair, notebook, and the model SSP-3 photometer. Figure 1-1 shows the SSP-3 photometer coupled to a Celestron C-8 telescope.

Unlike most photometers used in astronomy which employ a photomultiplier tube, the SSP-3 uses a silicon PN-photodiode detector which allows detection from the UV to the near infrared with a single detector. Other advantages of the SSP-3 include: increased safety factor since only low voltages are used (photomultiplier tube voltages can exceed 1000 volts), freedom from damage when accidentally exposed to bright lights or rough handling, exceptional linearity over a 1,000,000/1 light range, and ease of use not usually found in this level of instrumentation.

As mentioned previously, the SSP-3 photometer and a telescope are the only instruments needed for measurements of variable stars. However, to further extend the utility of this instrument, an external output is made available for interface to a remote counter or computer. The SSP3CARD and SSP-3A option provide the user with a fully automated photometer system. Figure 1-2 shows the complete SSP-3 photometer system.

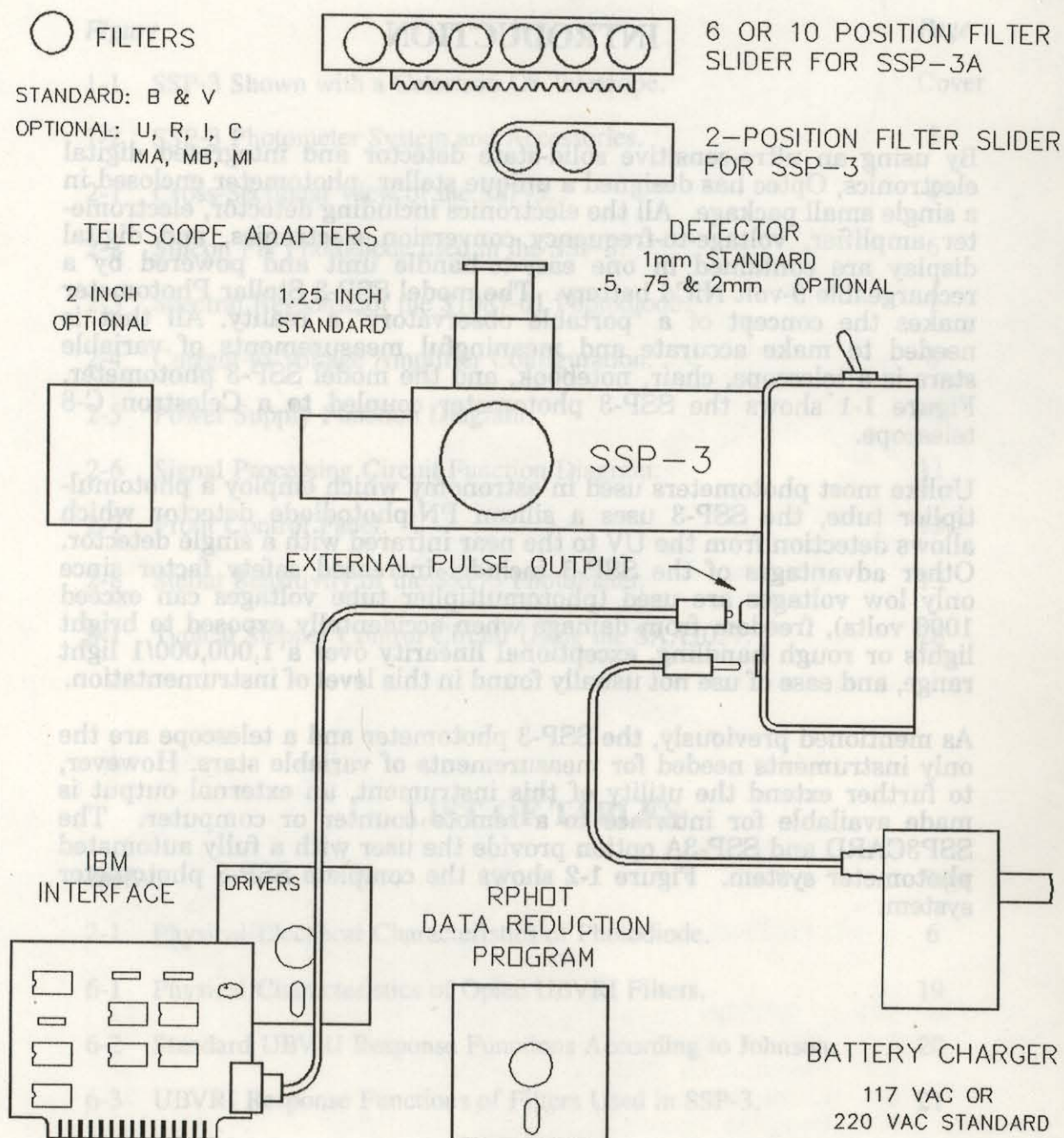


Figure 1-2. The SSP-3 Photometer System and Accessories.

SECTION 2.0

THEORY OF OPERATION

2.1 Basic Physical Characteristics

Figure 2-1 shows a cross-sectional view of the SSP-3 photometer. Light enters the photometer through the 1.25 inch telescope adapter and is directed either to the focusing eyepiece or the detector by means of a flip-mirror. The focusing eyepiece consists of a 1 inch focal length Ramsden and a reticle with a precisely scribed ring that defines the detector field of view. A green LED illuminates the reticle from the side. After a star is centered in the ring, the flip mirror is rotated to expose the detector. It is important to note that, unlike a photomultiplier system, the image of the star falls on the detector plane; a Fabry lens is not used.

Focusing Eyepiece

No Fabry Lens

*Detector Surface
Uniformity*

To insure uniform surface response, each detector is inspected under a microscope for surface defects that could cause a signal drop if the star's image was centered upon it. Actual optical bench tests of stock units with a 0.002 inch diameter spot (equivalent to a 5 arc second stellar seeing disk with an 80 inch focal length telescope) typically show less than a 1% response variation over the surface. Since testing each unit for surface uniformity with a scanning spot is time consuming and thus expensive, only a few units of each production run are tested. The user can test the uniformity of his detector by observing the readings of a bright star on a very stable night (use the 1 scale to minimize instrument noise) in several locations around the detector. If the response varies by more than 1% within a circle measuring 0.7 times the diameter of the reticle ring, Optec will replace the detector under our warranty terms.

Filter Slider

*Johnson B & V
Filters*

A two-position filter slider is mounted between the flip mirror and the detector. Any pair of filters selected by the user before delivery can be mounted in the slider. Since the slider is easily pulled out of the unit, sliders with other combinations of filters can be inserted. For most variable star work, a single slider with B and V filters is recommended to begin with. See Section 6.0 for a description of the standard UBVRI filter system and Section 7.0 for a description of the MA, MB and MI Wing filter set.

Use of Clear Filter

For observations which do not require a filter such as occultation timing, asteroid rotation, and minimum timing of binary systems, the Clear filter is used to insure that the proper optical distance is maintained. Without the Clear filter, the stellar image will be out of focus on the detector and the size of the blur circle would be proportional to the telescope's f/number.

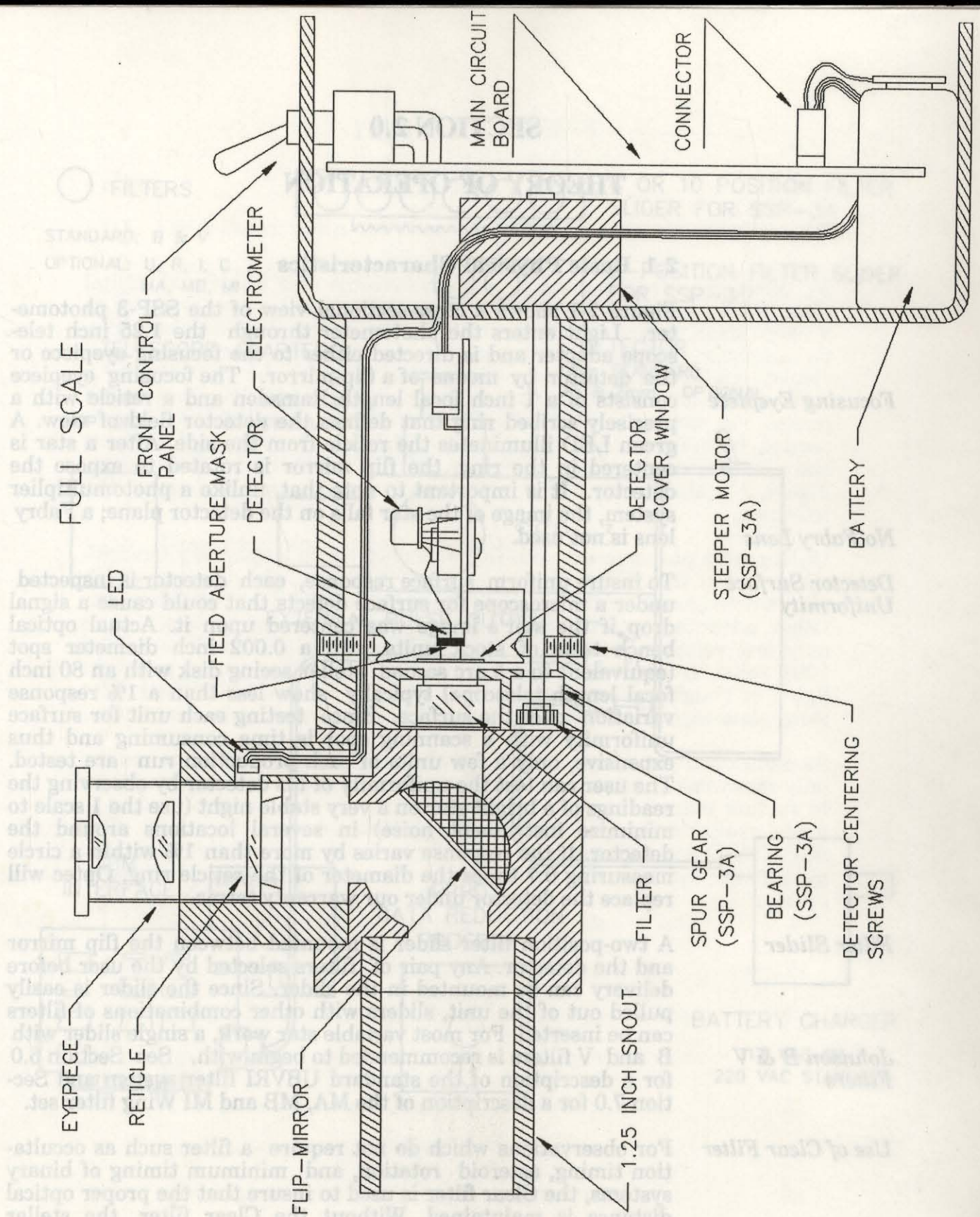


Figure 2-1. Cross-Sectional View of the SSP-3.

<i>Detector Mounting</i>	The detector and electrometer are rigidly mounted behind the filter slider on an X-Y adjustable V-grooved bracket. Accurate alignment of this bracket on an optical bench insures that the sensitive area of the detector matches the stellar field as defined by the reticle in the focusing eyepiece. The field diameter is determined by a mask which is placed on top of the photodiode.
<i>Field Apertures</i>	Sizes of 0.5, 0.75, 1.0 and 2.0 mm are available with the 1.0 mm size considered best for most telescopes with focal lengths in the range of 50 to 150 inches. See Appendix B for determination of the angular size for typical aperture/telescope combinations.
<i>Electrometer</i>	The electrometer amplifies the current from the photodiode by a factor of 5×10^{10} and is analogous to the operation of a photomultiplier tube. From the electrometer amplifier, the signal is then routed to the voltage-to-frequency converter for final processing into counts based on a 1 or 10 second gate time interval. The resulting count is then read from the four-digit readout on the front panel or from an external counter/computer connected to the pulse output connector.
<i>Output Count</i>	

2.2 Detector Theory

<i>Detector Type</i>	The detector used in the SSP-3 is a model S1087-01 manufactured by Hamamatsu Corporation. This unit can be classified as a planar diffusion type which offers the highest possible shunt resistance value (R_s) resulting in a very low noise current. Figure 2-2 shows the construction of this type of device and Table 2-1 lists the important physical and electrical characteristics which are used in further analysis.
<i>Electron-Hole Pairs</i>	When light energy greater than the band gap energy is absorbed in the P or N layers of the photodiode, electrons are excited into the conduction band. This creates what is normally called an electron-hole pair in the silicon crystal structure which makes up the photodiode. Because of the intrinsic electric field generated across the P-N junction, electron-hole pairs created in this region are pulled apart with the electrons migrating to the N side and the holes migrating to the P side. If the P and N sides are connected by a wire, current will flow in the wire which is directly proportional to the light flux.
<i>Wavelength Dependency</i>	Photons of different wavelength penetrate to different depths in the photodiode before being absorbed. Blue photons are absorbed quickly near the surface of the P layer and red photons are absorbed deep in the N layer. Since recombination can occur before the electron or hole moves across the junction to its respective electrode, the probability of successful migration is strongly dependent on how near the junction the electron-hole pair is created. The electrical term which results from this probability-wavelength relationship is called spectral response which, more precisely, is the ratio of photocurrent in amperes to the amount of incident light power in watts at a given wavelength. Figure 2-3 shows a plot of the spectral response for the S1087-01 photodiode.
<i>Responsivity Defined</i>	

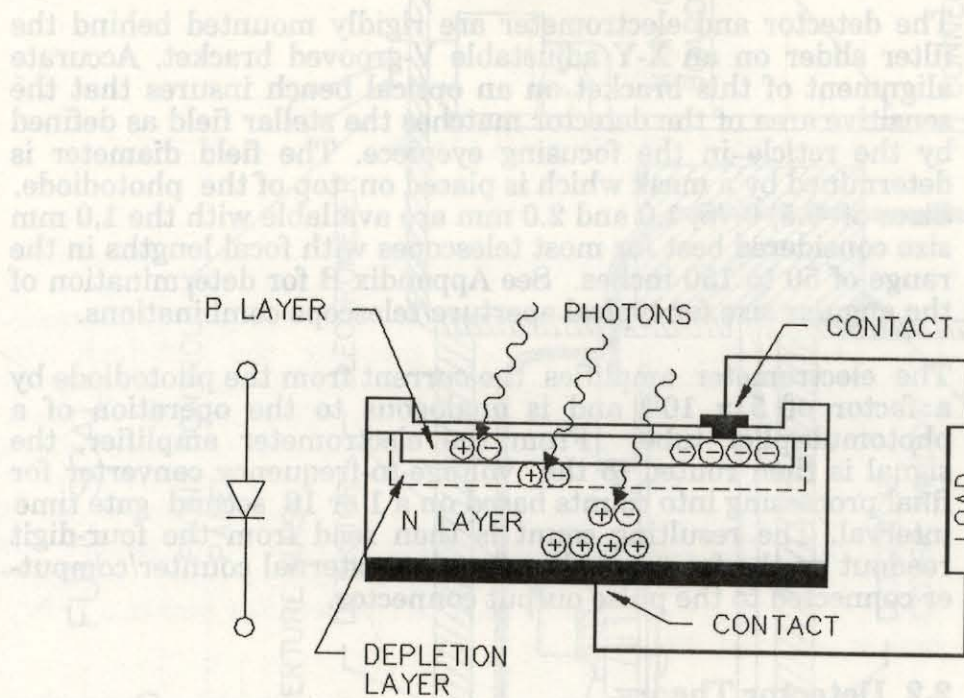


Figure 2-2. Planar Diffusion Type Silicon PN Photodiode used in the SSP-3.

Size	1.3 x 1.3 mm
Effective Area	1.6 sq. mm
Spectral Range	300 - 1100 nm
Peak Response	0.55 A/W at 940nm
Response at 550nm	0.34 A/W
Shunt Resistance	50 G Ω typical
Noise Equivalent Power	8×10^{-16} W/ $\sqrt{\text{Hz}}$

Table 2-1. Physical and Electrical Characteristics of the Model S1087-01 Photodiode.

Quantum Efficiency Defined

Photomultiplier and Photodiode Compared

Quantum efficiency is defined as the ratio of number of incident photons to the resulting photoelectrons in the output current. Since about 75% of the incident photons are absorbed in the wavelength band from 400 to 1000nm, the S1087-01 photodiode has a Q.E. of approximately 0.75 in this band. When compared to most photomultiplier tubes which have a Q.E. of about 0.10, the superior efficiency of the photodiode hence its output is significantly compromised by thermal noise sources in the diode and the associated amplifier. Because of these noise sources, the overall sensitivity of the SSP-3 is less than a photomultiplier photometer at some wavelengths. Only at very cold temperatures, liquid nitrogen at 77K for example, can the silicon photodiode equal and in many cases surpass the sensitivity of a photomultiplier tube due to its higher quantum efficiency.

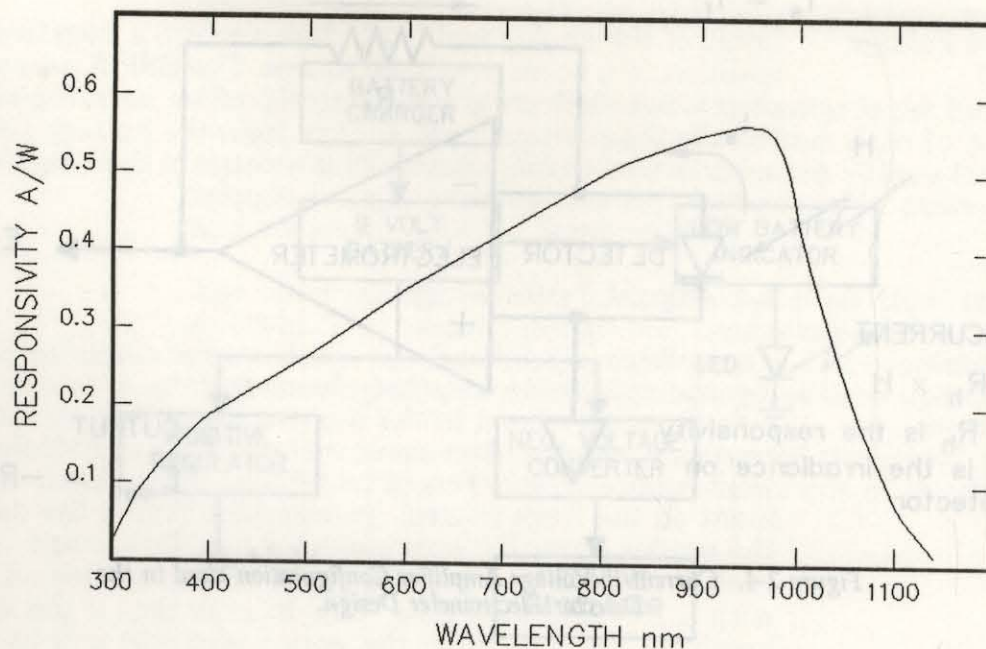


Figure 2-3. Spectral Response of the S1087-01 Photodiode Detector.

2.3 Detector/Electrometer Design

Typical Photo-Currents Measured

Observing an 8th magnitude star with an 11 inch aperture telescope and SSP-3 photometer with a V filter in place will produce a photocurrent (output from the detector) of about 0.01 picoamp (1×10^{-14} A). This extremely small current must be amplified and converted to a voltage of sufficient amplitude without introducing significant amounts of current and voltage noise. Thus, the electrometer's task is as important as the detector itself. The Detector/Electrometer circuit is the heart of the SSP-3 photometer and its design is a matter of optimizing both key elements as a single working unit.

Current-to-Voltage Amp

Figure 2-4 shows the basic current-to-voltage amplifier configuration used in the SSP-3. Photocurrent from the detector is balanced by an equal current in the feedback resistor, but flowing in the opposite direction so that the inverting input is kept near zero potential. The output voltage is thus:

$$E_{\text{out}} = -R_f \times I_s$$

where R_f is the feedback resistance and, in the case of the SSP-3, is equal to 50 G ohm (5×10^{10}). The photocurrent from the photodiode is I_s . In the above example observing an 8th magnitude star, the 0.01 picoamp photocurrent results in a 0.0005 V output from the amplifier.

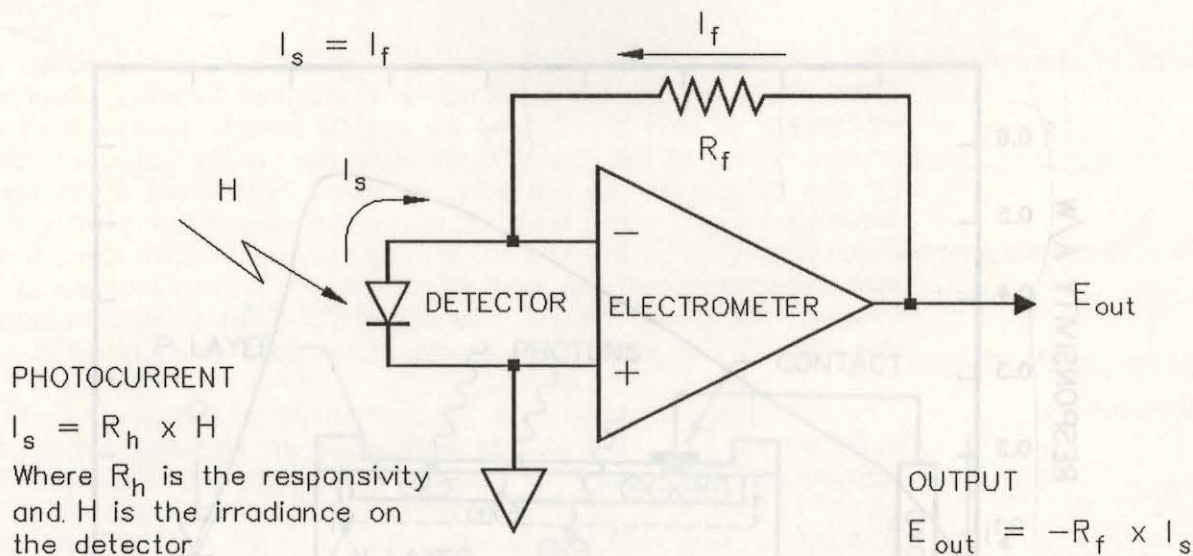


Figure 2-4. Current-to-Voltage Amplifier Configuration Used in the Detector/Electrometer Design.

Gain Stability

Of course, the gain stability of this circuit is highly dependent on the resistance stability of the feedback resistor. Fluctuations of its value due to temperature changes could cause gain errors during observations which are specially objectionable when all-sky photometry is done. The special resistor used has a temperature coefficient of 200 ppm/°C which is extremely low for a resistor of its size and rating. Thus, a 20°C drop in temperature during the night which is not uncommon, would cause a 0.004 magnitude error in electrometer gain. Even though this error source can be safely ignored, temperature effects on the responsivity of the detector and passbands of the filters also have to be considered when extreme temperature changes do occur.

Surface Leakage Currents

Since extremely small currents are amplified, surface leakage currents may effect the overall accuracy of the Detector/Electrometer circuit. To protect against this, the finished circuit is baked at an elevated temperature in a vacuum dessicator for several days before it is heavily coated with a silicon sealant which has a very high bulk resistance. During the cure time, which also may last several days, the finished circuit is stored in a vacuum dessicator until mounted in the SSP-3.

2.4 Power Supply

Power Supply Design

An important consideration in the design of the SSP-3 photometer was the need for a stable positive and negative power supply. It was decided that the unit should be totally portable, and should be able to run for at least five hours between charges. If this was not enough time, then the unit should be able to run on a common alkaline battery or another rechargeable battery. These objectives were all achieved using the power supply design shown in Figure 2.5.

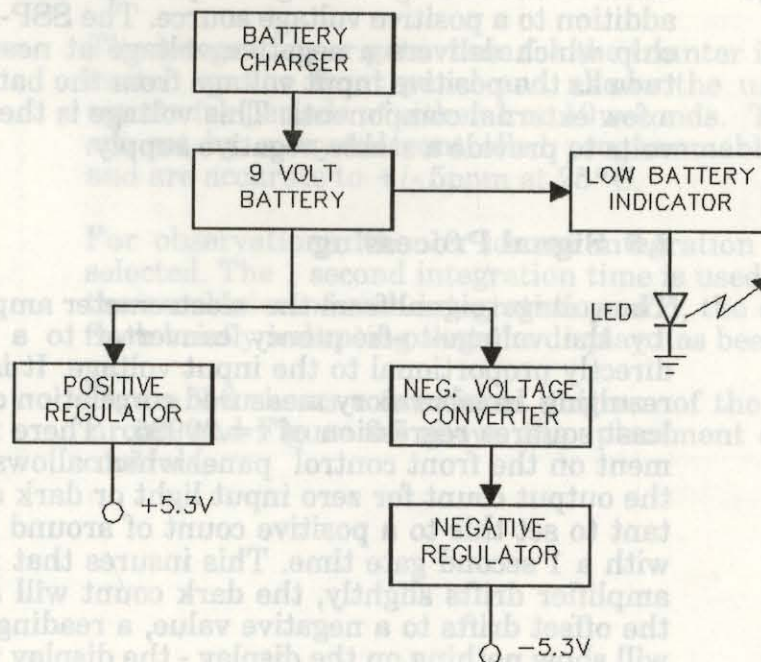


Figure 2-5. Power Supply Function Diagram.

Battery Charger

The first block represents the Battery Charger which is similar in design and appearance to the common calculator charger. It delivers one of two charge rates to the battery, depending on whether the unit is on or off. If it is off, a trickle charge is applied which will fully charge the battery in approximately 15 hours. If the unit is on, enough current will be delivered to run the unit and charge the battery at the same time. Located on the back of the unit is a 2.5 mm jack to connect the charger.

NiCd Battery

The second part of the supply consists of a 9 volt NiCd rechargeable battery available from General Electric (model GC9) or Gould (model GS9T). This battery can be purchased from any well-equipped hardware or department store for about \$10.00. One battery is supplied with the unit when purchased.

Battery Life

The battery can be used alone for at least five hours, or indefinitely with the charger attached. In addition, a common 9 volt radio battery may be substituted if the battery is drained and there isn't time or power available for recharging it. There is also a low battery indicator on the front panel. This will light up to signal that the battery needs to be recharged or replaced before the low battery condition affects the readings.

Voltage Regulation

The voltage from the battery is regulated to a constant 5.3 volts by the positive regulator. This provides a stable source for the electrometer amplifier and other electronics.

Negative Voltage

Some of the analog and logic chips require a negative voltage in addition to a positive voltage source. The SSP-3 uses an ICL7660 chip which delivers a negative voltage at near the same amplitude as the positive input voltage from the battery and uses only a few external components. This voltage is then regulated at -5.3 volts to provide a stable negative supply.

2.5 Signal Processing

Voltage-to-Frequency Conversion

Linearity

The voltage signal from the electrometer amplifier is processed by the voltage-to-frequency converter to a frequency that is directly proportional to the input voltage. It is extremely linear, resulting in laboratory measured correlation coefficient using a least squares regression of $r = .99995$. There is an offset adjustment on the front control panel which allows the user to select the output count for zero input light or dark count. It is important to set this to a positive count of around five on the 1 scale with a 1 second gate time. This insures that if the electrometer amplifier drifts slightly, the dark count will still be above 0. If the offset drifts to a negative value, a reading of the dark count will show nothing on the display - the display will be dark.

Scale Control

The SCALE adjustment is located in the center of the front panel and consists of a three position switch labeled 1, 100, and 10. This control sets the electrometer voltage that will result in a full scale input frequency of 10K hertz. On 1, the least sensitive scale, an input of -6.6 volts corresponds to 9999 counts; however, since the highest electrometer output voltage is about -4.0 at saturation, the highest display will be around 6500 counts on this scale. Usually, only zero or first magnitude stars will saturate the electrometer. On the 10 and 100 scales, the electrometer output corresponds to -660 mv and -66 mv respectively. The user can adjust the gain, much in the same way it is done with a DC amplifier/photometer, to keep the signal reading as near as possible to full scale. By doing this, errors due to quantumization become insignificant.

External Pulse Output

This frequency is also available at a jack on the back of the unit above the battery charger input. It may be used to connect to the Optec SSP3CARD, a small computer, an external counter, or other digital recording equipment. When the SCALE adjustment is set correctly so there is no overflow, the frequency will range from 0 to 10K hertz. The output pulses are positive going with a pulse width of around 25 micro-seconds, an amplitude of 5.0 volts, and sufficient power to drive two TTL gates.

4-Digit Display

The display makes use of a combination counter/display driver chip from Intersil. It provides a four digit output, which is used to drive the display on the front panel. The count displayed will range from the offset count to a full count reading of 9999. If the scale or gate time is set too high for a given star brightness, an overflow will result. This is indicated by the LED on the front panel located to the right of the display. If this condition occurs,

the user should reduce the SCALE factor or gate time to lower the count.

Integration Time

The integration or gate time for the counter is set by the TIME switch on the front panel and allows the user to accumulate counts for periods of either 1 or 10 seconds. These time periods are set by a crystal controlled programmable pulse generator and are accurate to $\pm 5\text{ppm}$ at 25°C .

For observations, the 10 second integration time is normally selected. The 1 second integration time is used for setup only. At the conclusion of each integration period, the overflow LED will flash briefly indicating that the display has been updated.

Figure 2.6 shows a functional diagram of the signal processing circuit and Figure 2.7 shows the placement of the front panel controls.

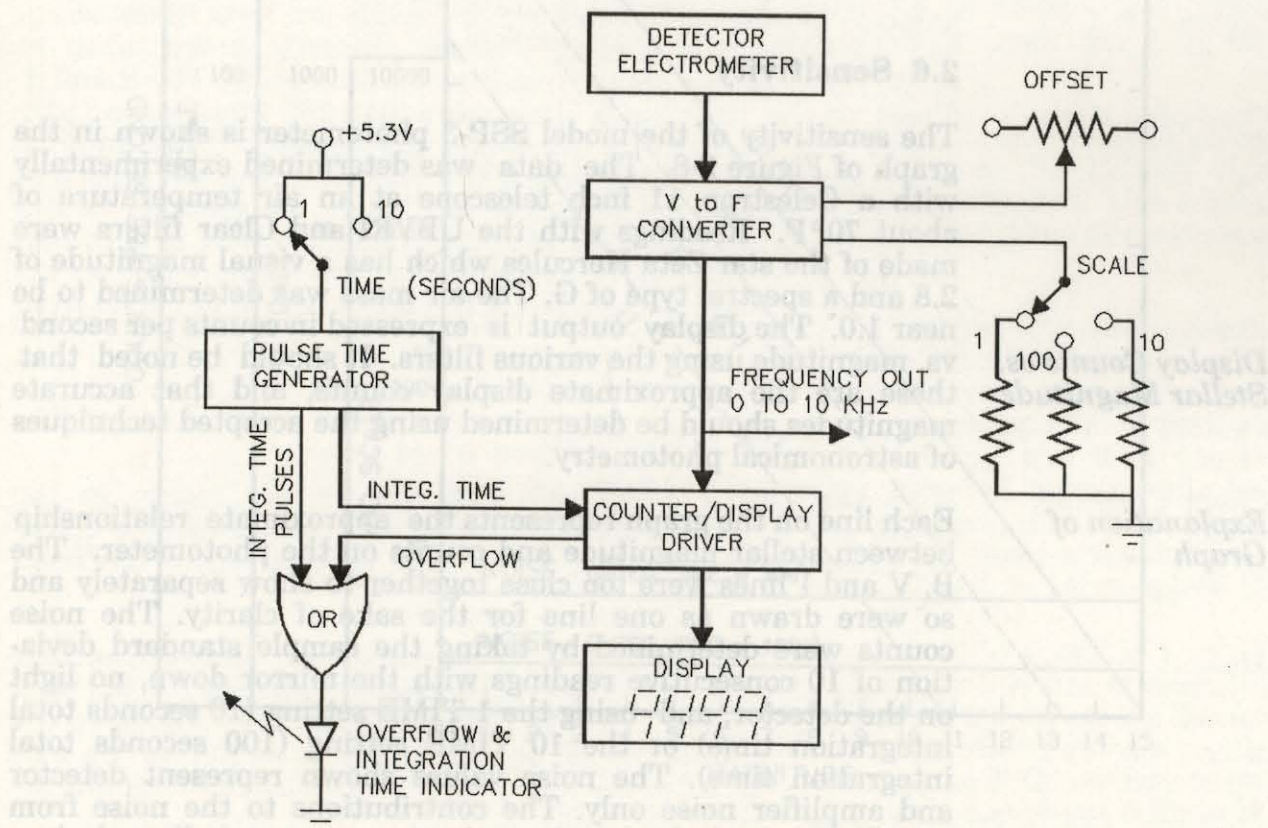


Figure 2-6. Signal Processing Circuit Function Diagram.

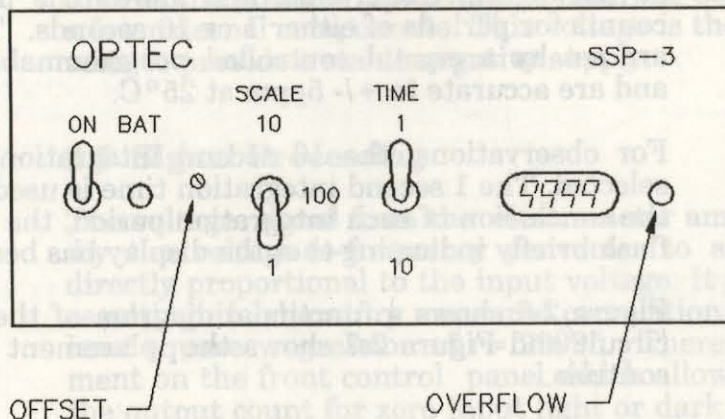


Figure 2-7. Front Control Panel.

2.6 Sensitivity

The sensitivity of the model SSP-3 photometer is shown in the graph of Figure 2-8. The data was determined experimentally with a Celestron 11 inch telescope at an air temperature of about 70°F. Readings with the UBVRI and Clear filters were made of the star Zeta Hercules which has a visual magnitude of 2.8 and a spectral type of G. The air mass was determined to be near 1.0. The display output is expressed in counts per second vs. magnitude using the various filters. It should be noted that these are the approximate display counts, and that accurate magnitudes should be determined using the accepted techniques of astronomical photometry.

Each line on the graph represents the approximate relationship between stellar magnitude and counts on the photometer. The B, V and I lines were too close together to show separately and so were drawn as one line for the sake of clarity. The noise counts were determined by taking the sample standard deviation of 10 consecutive readings with the mirror down, no light on the detector, and using the 1 TIME setting (10 seconds total integration time) or the 10 TIME setting (100 seconds total integration time). The noise values shown represent detector and amplifier noise only. The contributions to the noise from scintillation and changes in extinction are not indicated since they are too dependent on observing conditions. Shot noise from the sky and star are insignificant at these levels and can be ignored.

For the sake of comparison when observing dim stars, the intersection of the diagonal UBVRI and CLEAR lines and the horizontal noise lines determine at what magnitude the signal-to-noise ratio is 1 for the 10 and 100 second integration times. For example, to obtain 0.01 magnitude accuracy, a signal to noise ratio of 100 to 1 is needed. Thus, with an 11 inch telescope and 100 seconds of integration time, stars of magnitude 7.0 may be measured to 0.01 magnitude accuracy with the B, V and I filters. Similarly, stars of magnitude of 9.5 could be measured to 0.1 magnitude accuracy.

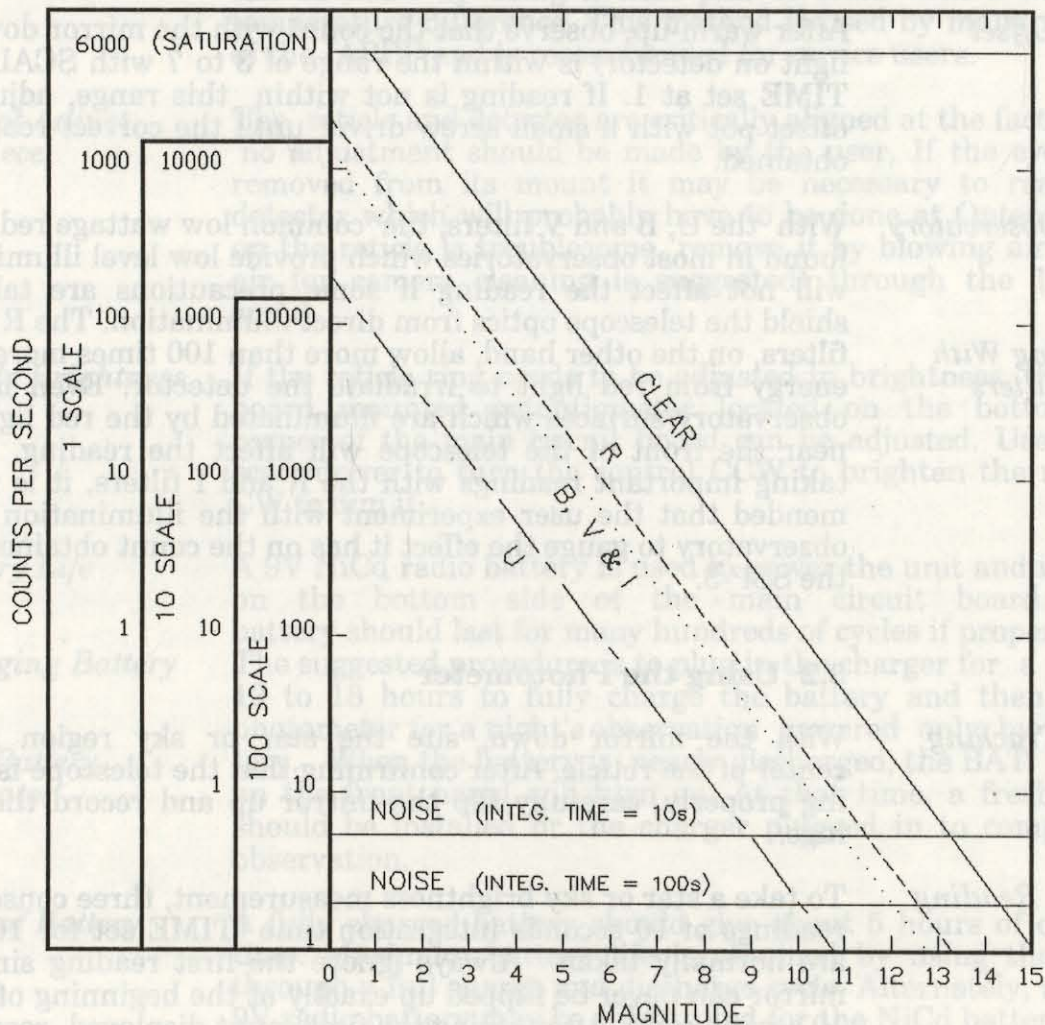


Figure 2-8. Counts per Second vs. Stellar Magnitude. These are Typical Values Obtained with an 11 Inch Aperture Telescope.

SECTION 3.0

OPERATING PROCEDURE

3.1 Check-out List

Clean Filters

Remove the filter slider and clean filters, only if necessary, with a cotton swab dipped in alcohol or lens cleaning fluid. Do NOT rub hard.

Warm-up Time

Before taking readings, turn the photometer on and allow at least 10 minutes warm-up time at observatory temperature.

Adjust Offset

After warm-up, observe that the count with the mirror down (no light on detector) is within the range of 3 to 7 with SCALE and TIME set at 1. If reading is not within this range, adjust the offset pot with a small screw driver until the correct reading is obtained.

Check Observatory Lights

With the U, B and V filters, the common low wattage red lights found in most observatories which provide low level illumination will not affect the reading if some precautions are taken to shield the telescope optics from direct illumination. The R and I filters, on the other hand, allow more than 100 times more light energy from red light to irradiate the detector. Even interior observatory surfaces which are illuminated by the red light and near the front of the telescope will affect the reading. Before taking important readings with the R and I filters, it is recommended that the user experiment with the illumination in his observatory to gauge the effect it has on the count obtained from the SSP-3.

Observing With R & I Filters

3.2 Using the Photometer

Check Tracking

With the mirror down, site the star or sky region in the center of the reticle. After confirming that the telescope is tracking properly, carefully flip the mirror up and record the readings.

Make A Reading

To take a star or sky brightness measurement, three consecutive readings of 10 seconds integration time (TIME set for 10) each are normally taken. Always ignore the first reading since the mirror can never be flipped up exactly at the beginning of a new 10 second cycle. After seeing the first count displayed, record the next three.

Check Tracking

After the reading sequence is completed, return the mirror to the viewing position and confirm that the star is still centered properly in the reticle. Normally, if the star is within a circle of 0.35 radius of the scribed ring center, more than 99% of the

star's light has been collected by the detector. This rule of thumb does depend on seeing quality.

At this point, the user has successfully completed making a reading and is referred to other sources of information about stellar photometry.

3.3 Calibration, Adjustments, and Battery Maintenance

Filter Calibration

For precise determination of stellar magnitude, the filters used in the SSP-3 must be calibrated with standard stars. The procedure for doing this is beyond the scope of this manual and the user is referred to the IAPPP organization and standard texts on photometry. Simple determination of filter correction factors can be made by using a close pair of stars with a wide color temperature difference. This method is used by many members of the IAPPP and is recommended for novice users.

Do Not Adjust Eyepiece

The reticle and detector are critically aligned at the factory and no adjustment should be made by the user. If the eyepiece is removed from its mount it may be necessary to realign the detector which will probably have to be done at Optec. If dust on the reticle is troublesome, remove it by blowing air (canned air for camera cleaning is suggested) through the 1.25 inch snout.

Reticle Brightness

If the reticle ring needs to be adjusted in brightness, the circuit board mounted potentiometer located on the bottom right corner of the main circuit board can be adjusted. Use a small screwdriver to turn the control CCW to brighten the reticle or CW to dim it.

Battery Life

A 9V NiCd radio battery is used to power the unit and is located on the bottom side of the main circuit board. This battery should last for many hundreds of cycles if properly used.

Charging Battery

The suggested procedure is to plug in the charger for a period of 12 to 18 hours to fully charge the battery and then use the photometer for a night's observation powered only by the battery. When the battery is nearly discharged, the BAT indicator on the front panel will turn on. At that time, a fresh battery should be installed or the charger plugged in to complete the observation.

Low Battery Indicator

Care of Battery

A fully charged battery should give about 5 hours of operating time. Maximum battery life is obtained by using the battery through a full charge and discharge cycle. Alternately, a regular 9V radio battery may be substituted for the NiCd battery to give longer operating time. An alkaline battery has about 5 times the capacity of a NiCd battery, thus 25 hours of total operating time can be expected.

IMPORTANT: Make sure the photometer is turned off before the charger is plugged in or a new battery installed.

SECTION 4.0

TROUBLE-SHOOTING GUIDE

The following common problems and solutions have been collected over the years from our customers and our attempts to solve their instrument problems. Before calling us, read through these and relevant sections of this manual to see if an easy solution exists for your errant photometer.

- 1) **Unit has been turned on and left to warm up for the proper time but no display is seen unless light is incident on the detector.**

With a small screw driver adjust the offset control pot on the front panel. (See Figure 2-7.) With no light incident on the detector, rotate the control pot CCW for at least 20 turns to make sure a display value is seen and then rotate CW until a count of 5 is obtained with the GAIN and TIME set for 1.

- 2) **The dark count (no light on the detector) appears to drift with time and temperature beyond what you have been accustomed to.**

This could be a serious problem if the drift is due to a break in the moisture seal protecting the detector/electrometer assembly. The unit should always be kept in a dry and warm environment when not used. Place the unit in a sealed container with about 4 ounces of activated desiccant for a period of 48 hours. If desiccant is not available, use a 100 watt spot light placed about 2 feet from the unit for a similar length of time. Allow the unit to come to ambient temperature before measuring the drift. If the problem does not disappear or reduce to acceptable levels, it will have to be returned to Optec for repair.

- 3) **When you first turn the unit on, a display count is seen momentarily and then disappears. Adjustments to offset do not work. The integration LED flashes in the usual manner and the battery is good.**

This may simply indicate the detector is saturated. Be sure that no light is reaching the detector. The most common chip to fail in the SSP-3 is the ICL7217 counter chip from Intersil. Experience has shown the above symptom occurs when this chip fails in the usual way. Since the chip is socketed, the part can be easily replaced. Contact Optec for a replacement.

- 4) **The unit seems to drift and give erratic readings with the I and R filters but appears to work OK with the B and V filters.**

Read Section 3.1 again. In addition to observatory or nearby incandescent light causing problems, high cirrus clouds not visible with the naked eye or an active aurora can cause havoc in the far red and infrared portions of the spectrum and

be invisible in the visible portion.

- 5) **The unit appears to give much higher than expected counts every once in a while.**

If the unit is powered by the charger, any surge in the power line may cause an increase in the number of counts for the integration interval. Refrigerator compressors, dome motors, and telescope position servos could easily be the cause of this problem. The best solution is to use the unit with the battery alone. If observations longer than 4-5 hours need to be done, use a regular 9 volt alkaline radio battery instead of the NiCd battery. This type of battery will power the unit for about 25 hours. Vibration and strong radio signals may also be the cause of the problem.

- 6) **The night appears clear but the star count is diminishing with time faster than expected due to changing extinction conditions.**

A common problem specially with Celestron and Meade telescopes is that a nearly invisible film of condensed water will develop on the corrector plate or main mirror during the night if the dew point is high enough. Usually this fog film can only be seen when a strong light is projected down the front of the telescope and the optics carefully inspected. A hair dryer is the only cure. "Dew-zappers", low wattage heaters designed to fit over the front cell, are now commonly available to avoid this condensation problem.

- 7) **As the star approaches the edge of the detector the count begins to fall but it looks as if the star is still completely within the ring as seen in the eyepiece.**

The stellar light profile (energy vs. radius from the center of the star) is much larger than what is seen. On a good night a seeing disk could appear to be about 2 arc second in diameter. However, to capture over 99% of the energy a detector diameter (field aperture) of over 20 arc seconds is needed. A hazy night or a night with much greater turbulence could increase the stellar profile many more times. Thus, care must be taken to keep the star from drifting near the edge of the detector since some of the incident energy will be lost.

- 8) **An external counter or computer (not the SSP3CARD) is connected to the SSP-3 and the count displayed on the photometer is significantly different when compared to the count recorded on the external device.**

It is possible for extra noise counts to be picked up on long signal cables if proper techniques are not followed. The SSP3CARD (Optec's IBM interface card) uses a Schmidt trigger input gate on the interface card to prevent small amounts of noise on the cable from affecting the count. Make sure that your external device has similar input noise protection. A shorter or shielded cable may also have to be used.

SECTION 5.0

SPECIFICATIONS

DETECTOR

Type	Silicon PN-photodiode
NEP	8×10^{-16} W/ $\sqrt{\text{Hz}}$ (typical)
Detector Size	1.3mm square (2.4mm square optional)
Spectral Range (5 % points)	300 to 1100 nm
Shunt Resistance	50 G Ohms (typical)
Surface Uniformity	<1 %

ELECTROMETER

Type	Current-to-Voltage
Bias Current	.15 pA Max.
Offset Voltage	< .25 mV
Open Loop Gain	100,000 V/V Min.
Closed Loop Gain (Rf)	5×10^{10}
Input Voltage Noise	4 μV (p-p) (.1 to 10Hz)
Input Current Noise	.003 pA (.1 to 10Hz)
Maximum Output Voltage	4.0 V

A/D CONVERTER

Type	Voltage-to-Frequency
Full Scale Frequency	10 KHz
Full Scale Input Voltages	-66 mV (100 SCALE) -660 mV (10 SCALE) -6.6 V (1 SCALE)
Linearity	<0.3 %
Offset	<.5mV (adjustable to 0)

COUNTER/DISPLAY

Integration Times (Gate)	1 and 10 seconds
Timer	Quartz crystal programmable timer
Timer Accuracy	+/-5ppm at 25°C
Display	4-digit (9999)
Character Height/Color	.11 inch, Red

POWER SUPPLY

Battery	9 volt NiCd (Type GE GC9 or Gould GS9T)
Operating Time	5 hours at 65°F 4 hours at 20°F
Capacity	90 mA hours
Recharge Time	12 to 18 hours
Battery Charger	12 volts DC, 200 mA

EYEPIECE

Focal Length	25 mm
Type	Ramsden
Reticle Illumination	Green LED
Field of View (80 inch FL)	0.4 degrees

MECHANICAL

Body Material	Aluminum 6061-T6 alloy
Finish	Bright Dip Black Anodized
Overall Length	9 inches (tip to tip)
Weight	2 lbs. 14 oz.
Telescope Coupler	1.25 inch (standard)

SECTION 6.0

JOHNSON UBVRI FILTERS

Filter-Detector Response Defined

The UBVRI filter system established by Johnson is generally followed today and exactly defines color bands in the spectrum interval from 300 to 1200 nm. Table 6-2 lists the filter-detector responses of this system as originally established by Johnson. Filter-detector response is defined as the normalized product of filter transmission times detector response for each wavelength interval. Table 6-3 lists the filter-detector responses for the filters used with the SSP-3.

OPTEC Filters

The OPTEC UBVRI filters are all made from combinations of Schott colored glass. The glass types and thicknesses for each filter has been computer optimized for the best fit with the Johnson standards. The exact glass formulas are proprietary but complete filters can be purchased separate from the photometer for those persons constructing their own solid-state photometer.

Johnson & OPTEC Compared

As can be seen from Tables 6-2 and 6-3, the B, V, R and I filters match closely the standard Johnson values and give correspondingly small correction coefficients. Blocking the red leak of the glass used in the U filter results in loss of UV transmission from 300 to 350 nm. The filter is still useful for comparison purposes even though it does not transform into the standard Johnson system precisely. It is interesting to note that the U filter is the most difficult one to transform accurately for all observers including those with photomultiplier systems. UV transmission through the atmosphere varies considerably and any optical glass in the telescope (corrector lens) or photometer will absorb light shorter than 350 nm making accurate U magnitude determinations difficult at best.

For those persons interested in the exact filter transmission and detector responsivity, Table 6-4 has been prepared using the latest filter and detector batch data. Filter characteristics are subject to change since we continually review our filter formulas and attempt to achieve near zero transformation coefficients.

Flatness	6 fringes Max.
Surface Quality	scratch and dig 80-50
Diameter	12.7 mm
Thickness	7 mm

Table 6-1. Physical Characteristics of Optec UBVRI Filters.

nm	U	B	V	R	I
300	0.00	----	----	----	----
310	0.10	----	----	----	----
320	0.61	----	----	----	----
330	0.84	----	----	----	----
340	0.93	----	----	----	----
350	0.97	----	----	----	----
360	1.00	0.00	----	----	----
370	0.97	----	----	----	----
380	0.73	0.11	----	----	----
390	0.36	----	----	----	----
400	0.05	0.92	----	----	----
410	0.01	----	----	----	----
420	0.00	1.00	----	----	----
440	----	0.94	----	----	----
460	----	0.79	0.00	----	----
480	----	0.58	0.02	----	----
500	----	0.36	0.38	----	----
520	----	0.15	0.91	0.00	----
540	----	0.04	0.98	0.06	----
560	----	0.00	0.72	0.28	----
580	----	----	0.62	0.50	----
600	----	----	0.40	0.69	----
620	----	----	0.20	0.79	----
640	----	----	0.08	0.88	----
660	----	----	0.02	0.94	----
680	----	----	0.01	0.98	0.00
700	----	----	0.01	1.00	0.01
720	----	----	0.01	0.94	0.17
740	----	----	0.00	0.85	0.36
760	----	----	----	0.73	0.56
780	----	----	----	0.57	0.76
800	----	----	----	0.42	0.96
820	----	----	----	0.31	0.98
840	----	----	----	0.17	0.99
860	----	----	----	0.11	1.00
880	----	----	----	0.06	0.98
900	----	----	----	0.04	0.93
920	----	----	----	0.02	0.84
940	----	----	----	0.01	0.71
960	----	----	----	0.00	0.58
980	----	----	----	----	0.47
1000	----	----	----	----	0.36
1020	----	----	----	----	0.28
1040	----	----	----	----	0.20
1060	----	----	----	----	0.15
1080	----	----	----	----	0.10
1100	----	----	----	----	0.08
1120	----	----	----	----	0.05
1140	----	----	----	----	0.03

Table 6-2. Standard UBVRT Response Functions According to Johnson.

SECTION 7.0

nm	U	B	V	R	I
300	0.00	----	----	----	----
310	0.00	----	----	----	----
320	0.00	----	----	----	----
330	0.16	----	----	----	----
340	0.41	----	----	----	----
350	0.63	----	----	----	----
360	0.92	0.05	----	----	----
370	1.00	0.18	----	----	----
380	0.82	0.38	----	----	----
390	0.37	0.59	----	----	----
400	0.00	0.75	----	----	----
410	0.00	0.86	----	----	----
420	0.00	0.97	----	----	----
440	----	1.00	----	----	----
460	----	0.74	0.00	----	----
480	----	0.42	0.00	----	----
500	----	0.24	0.60	----	----
520	----	0.10	0.95	0.00	----
540	----	0.04	1.00	0.05	----
560	----	0.01	0.88	0.06	----
580	----	0.00	0.62	0.26	----
600	----	----	0.34	0.55	----
620	----	----	0.14	0.77	----
640	----	----	0.04	0.92	----
660	----	----	0.01	0.99	----
680	----	----	0.00	0.99	0.00
700	----	----	0.00	0.92	0.00
720	----	----	----	0.84	0.00
740	----	----	----	0.73	0.00
760	----	----	----	0.61	0.08
780	----	----	----	0.48	0.47
800	----	----	----	0.37	0.85
820	----	----	----	0.28	0.96
840	----	----	----	0.19	0.98
860	----	----	----	0.14	0.99
880	----	----	----	0.10	1.00
900	----	----	----	0.07	1.00
920	----	----	----	0.05	0.98
940	----	----	----	0.03	0.96
960	----	----	----	0.02	0.90
980	----	----	----	0.02	0.76
1000	----	----	----	0.01	0.59
1020	----	----	----	0.00	0.43
1040	----	----	----	----	0.27
1060	----	----	----	----	0.16
1080	----	----	----	----	0.08
1100	----	----	----	----	0.02
1120	----	----	----	----	0.01
1140	----	----	----	----	0.00

Table 6-3. UBVRI Response Functions of Filters Used in the SSP-3.

Wing, R. P., 1971, *Proceedings of the Conference on Late Type Stars*, ed. G. W. Lockwood and H. M. Dyer (IPNO Contribution No. 564), p. 145.

nm	U	B	V	R	I	DET. A/W
300	0.00	----	----	----	----	0.030
310	0.00	----	----	----	----	0.045
320	0.00	----	----	----	----	0.065
330	0.16	----	----	----	----	0.080
340	0.28	----	----	----	----	0.115
350	0.37	0.00	----	----	----	0.130
360	0.48	0.04	----	----	----	0.150
370	0.49	0.14	----	----	----	0.160
380	0.39	0.28	----	----	----	0.165
390	0.17	0.41	----	----	----	0.175
400	0.00	0.50	----	----	----	0.185
410	----	0.55	----	----	----	0.190
420	----	0.60	----	----	----	0.200
440	----	0.57	----	----	----	0.215
460	----	0.39	----	----	----	0.230
480	----	0.21	0.00	----	----	0.245
500	----	0.11	0.49	----	----	0.265
520	----	0.05	0.74	----	----	0.280
540	----	0.02	0.72	0.00	----	0.300
560	----	0.01	0.60	0.04	----	0.320
580	----	0.01	0.40	0.16	----	0.335
600	----	----	0.21	0.33	----	0.355
620	----	----	0.08	0.44	----	0.370
640	----	----	0.02	0.50	----	0.385
660	----	----	0.00	0.53	----	0.400
680	----	----	0.00	0.51	----	0.410
700	----	----	0.00	0.46	----	0.420
720	----	----	----	0.41	0.00	0.440
740	----	----	----	0.34	0.00	0.455
760	----	----	----	0.27	0.08	0.470
780	----	----	----	0.21	0.45	0.485
800	----	----	----	0.16	0.81	0.500
820	----	----	----	0.11	0.90	0.510
840	----	----	----	0.08	0.91	0.515
860	----	----	----	0.06	0.90	0.525
880	----	----	----	0.04	0.89	0.540
900	----	----	----	0.03	0.87	0.550
920	----	----	----	0.02	0.84	0.560
940	----	----	----	0.01	0.81	0.565
960	----	----	----	0.01	0.77	0.560
980	----	----	----	0.01	0.72	0.505
1000	----	----	----	0.01	0.66	0.430
1020	----	----	----	----	0.57	0.355
1040	----	----	----	----	0.49	0.270
1060	----	----	----	----	0.38	0.205
1080	----	----	----	----	0.28	0.140
1100	----	----	----	----	0.20	0.080
1120	----	----	----	----	0.14	0.040
1140	----	----	----	----	0.08	0.010

Table 6-4. Filter Transmission and Detector Responsivity in A/W.

SECTION 7.0

WING FILTERS

Measuring TiO Absorption

With the cooperation of Dr. Robert F. Wing of Ohio State University, Optec has designed three filters for the SSP-3 photometer which are useful in measuring the absorption of TiO (titanium oxide), and the true color temperature of late type stars such as Miras. These three filters labeled MA, MB and MI comprise a subset of the Wing 8-color system¹. See Table 7.1 for filter specifications.

It is widely known that the B-V color index of stars with spectral type K5 to M8 is nearly constant although the surface temperature of stars in this range vary considerably. The cooler the surface temperature of these stars the greater the TiO absorption in the visual band, which prevents the color index from becoming redder. As a result, the common B and V magnitude contain little useful information about these stars.

MA & MB Filters

Used together, the MA and MB filters measure the amount of TiO absorption in the star's outer atmosphere. The MA filter is centered on an absorption band at 712 nm and the MB filter is centered just off the band and on the continuum at 754 nm. The ratio of readings taken with these filters is proportional to the amount of TiO absorption.

MI Filter

The MI filter is centered on the continuum at 1025 nm. Readings taken with this filter and the MB filter can be used together to measure the slope of blackbody curve between these two points, and thus the temperature of the star may be calculated.

Advantages over B-V Photometry

Because these stars radiate most of their energy in the infrared and the SSP-3 is exceptionally sensitive for part of this band, very high instrument readings are obtained with these filters when only marginal readings are obtained in the B and V bands. In addition, the amount of background light from the atmosphere due to scatter from the moon or ground lights is nearly unmeasurable at these wavelengths which allows useful work to be done even when B and V photometry is impossible due to high sky readings.

Filter Name	Center Wavelength	Bandpass 1/2T points	Peak Transmission
MA	712 nm	10 nm	75 %
MB	754 nm	10 nm	75 %
MI	1025 nm	40 nm	55 %

Table 7-1. Specifications for Wing Filters.

¹ Wing, R. F., 1971, *Proceedings of the Conference on Late Type Stars*, ed. G. W. Lockwood and H. M. Dyck (KPNO Contribution No. 554), p. 145.

SECTION 8.0

SSP-3A OPTION

8.1 Physical Characteristics

The SSP-3A photometer is nearly identical in appearance and operation to the SSP-3 except for the addition of a motorized 6- or 10-position slider and 9-pin connector. The stepper motor is located under the control circuit board and connects to the filter slide rack by a pinion and shaft going through the photometer main body. See Figure 2-1.

Stepper Motor

The small 4-phase stepper motor is run on 12V DC power which is supplied through the 9-pin connector - it does not use power from the battery or charger. The important physical and electrical specifications for the motor used in the SSP-3A are listed in Table 8-1.

Number of Phases	4
Step Angle (full step)	7.5 degrees
Steps per Rev.	48
Holding Torque	2.8 oz.-in.
Operating Temp. Range	-15 to +50°C
DC Operating Voltage	12 volts
Resistance per Winding	70 Ω

Table 8-1. Specifications for Model PF35-48C Stepper Motor from Nippon.

8.2 Procedure for Determining Filter Position

Each filter position is separated by 33 full steps of the stepper motor. In order to determine position, 165 or more full steps in either direction are delivered by the stepper motor to home the slider against one side of its mounting. After this homing procedure, the computer or controller determines position by keeping track of the number of 33 step intervals from the home position. Stalling the motor against its mounting will not harm the motor or mounting covers in any way.

Finding Home Position

Pulse Rate to Motor

The pulse rate to the stepper can be varied under computer control and the optimum rate (fastest position change without losing steps due to slider inertia), with or without acceleration, must be determined experimentally. For a first approximation, try a steady pulse rate of 100 steps per second and observe whether the positions are kept accurately when changed repeatedly.

Allow Electrometer to Settle

After the proper position is obtained, it is important to wait approximately 1/2 second before starting an integration. The microphonics from moving the slider and the electrical noise generated by the high current pulse sent to the motor affect the detector/electrometer circuit by causing a momentary increase in the number of output pulses from the photometer. A short period of time is needed for the sensitive electronics to settle.

8.3 Connecting and Operating the Stepper Motor

If the SSP3CARD and associated cable are purchased with the SSP-3A, you can skip this section.

9-Pin Amp Connector

A 9-pin AMP connector is supplied with the SSP-3A for those wishing to design and build their own stepper controller or computer interface. Table 8-2 lists the pin numbers of the 9-pin connector which are connected to the motor and the proper step sequence that these lines must follow.

FUNCTION	T1	T2	T3	T4	COMMON
MOTOR WIRE COLOR	black	orange	brown	yellow	connect red & red
PIN NO. FOR SSP-3A CONN.	7	4	3	2	1
STEP 1	ON	ON	OFF	OFF	
SEQUENCE 2	OFF	ON	ON	OFF	
C.W. ROT. 3	OFF	OFF	ON	ON	
4	ON	OFF	OFF	ON	
1	ON	ON	OFF	OFF	

Table 8-2. Function and Color Code of Motor Wires.

Table 8-3 on the next page lists the pin numbers of the 9-pin AMP connector and their associated function. Either a shielded or unshielded 7-wire cable can be used. Since the amount of current used by the stepper motor is just a few hundred milliamps, small gauge wire can be used in the cable. Cables of lengths up to 100 feet have worked successfully.

Remove Battery When Using SSP3CARD

IMPORTANT: Power is supplied to the SSP-3A by the SSP3CARD through the 9-conductor cable (stock no. 17152). Remove the internal 9-volt battery and do not use the battery charger when using the SSP-3A in this mode. This is also applicable for custom installations when using pins 6 and 8 (Table 8.3) to supply power to the SSP-3A.

PIN #	COLOR	FUNCTION
1	CONNECT RED & RED	+12 TO STEPPER
2	YELLOW	T4 TO STEPPER
3	BROWN	T3 TO STEPPER
4	ORANGE	T2 TO STEPPER
5	GREEN	SIGNAL COMMON
6	ORANGE	+12 VOLTS DC
7	BLACK	T1 TO STEPPER
8	BROWN	POWER GROUND
9	GRAY	PULSE OUTPUT

Table 8-3. Pin Number and Function for the Motor Control Cable Connector.

8.4 Using the Signetics SAA1027 Stepper Driver

The Signetics SAA1027 stepper motor drive IC is available from Optec for a small charge. This 16-pin IC allows easy control of the stepper motor and requires only a few external resistors, a 12 V DC power source and a two control lines from the computer or controller. A typical circuit is shown in Figure 8-1.

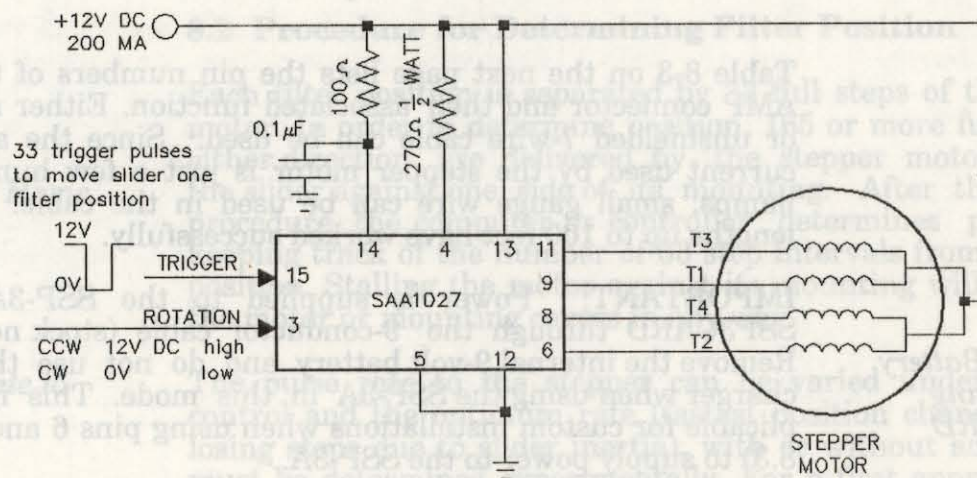
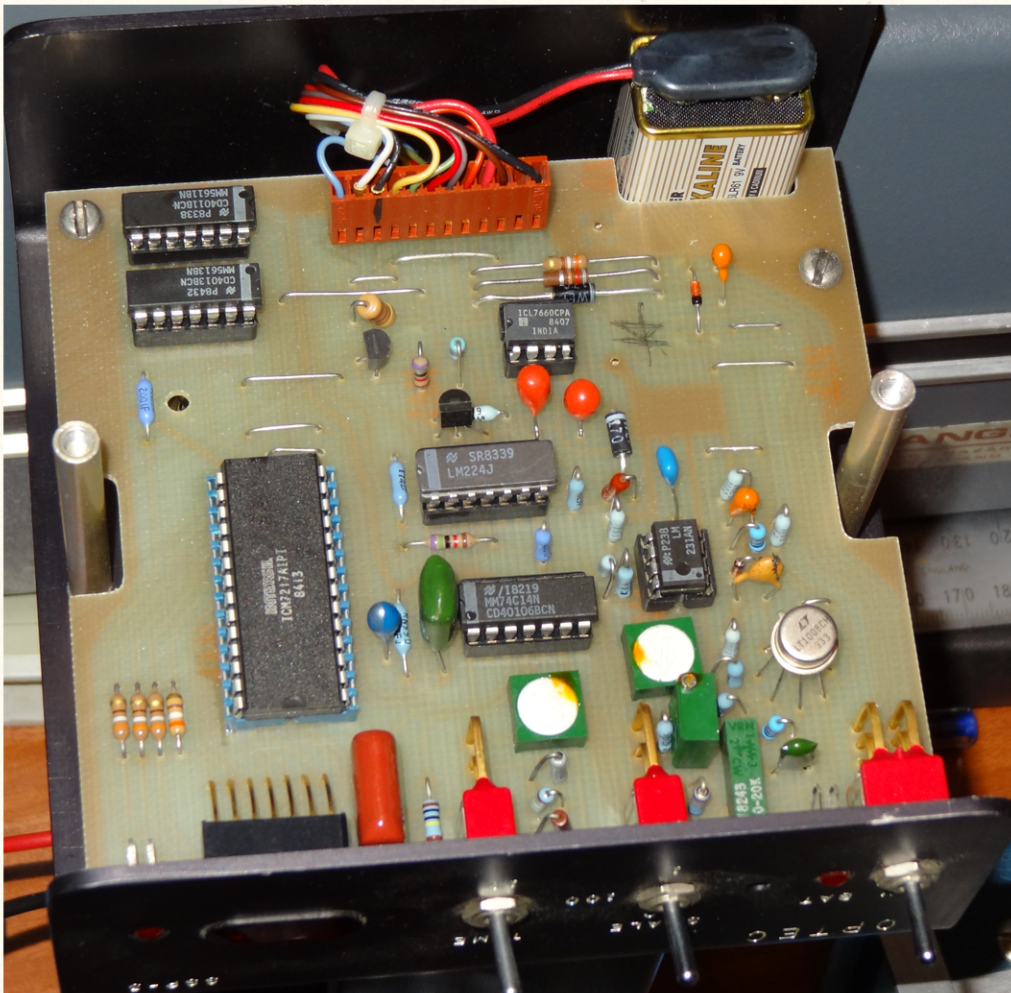
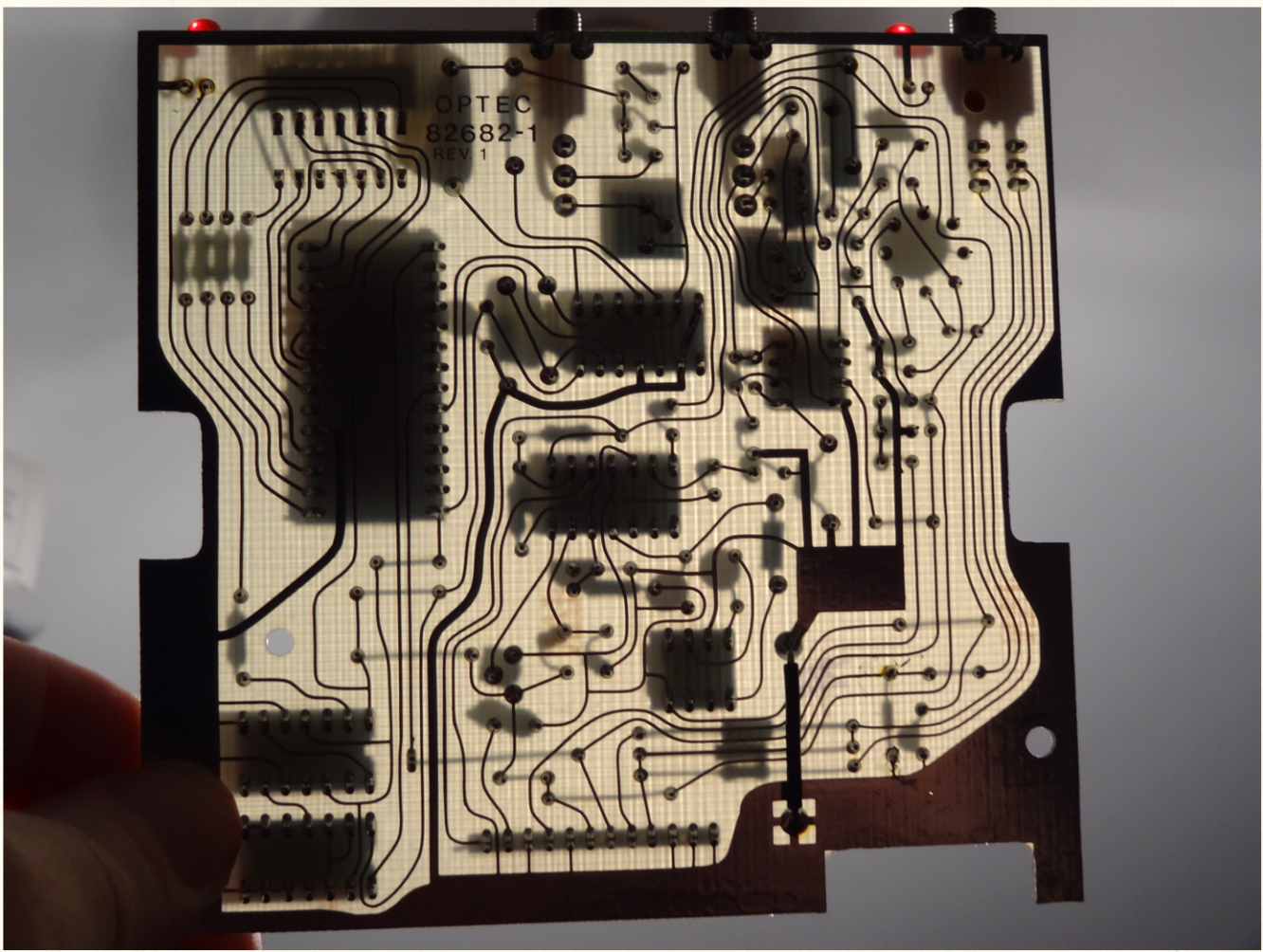


Figure 8-1. Typical Stepper Control Circuit Using the SAA1027.

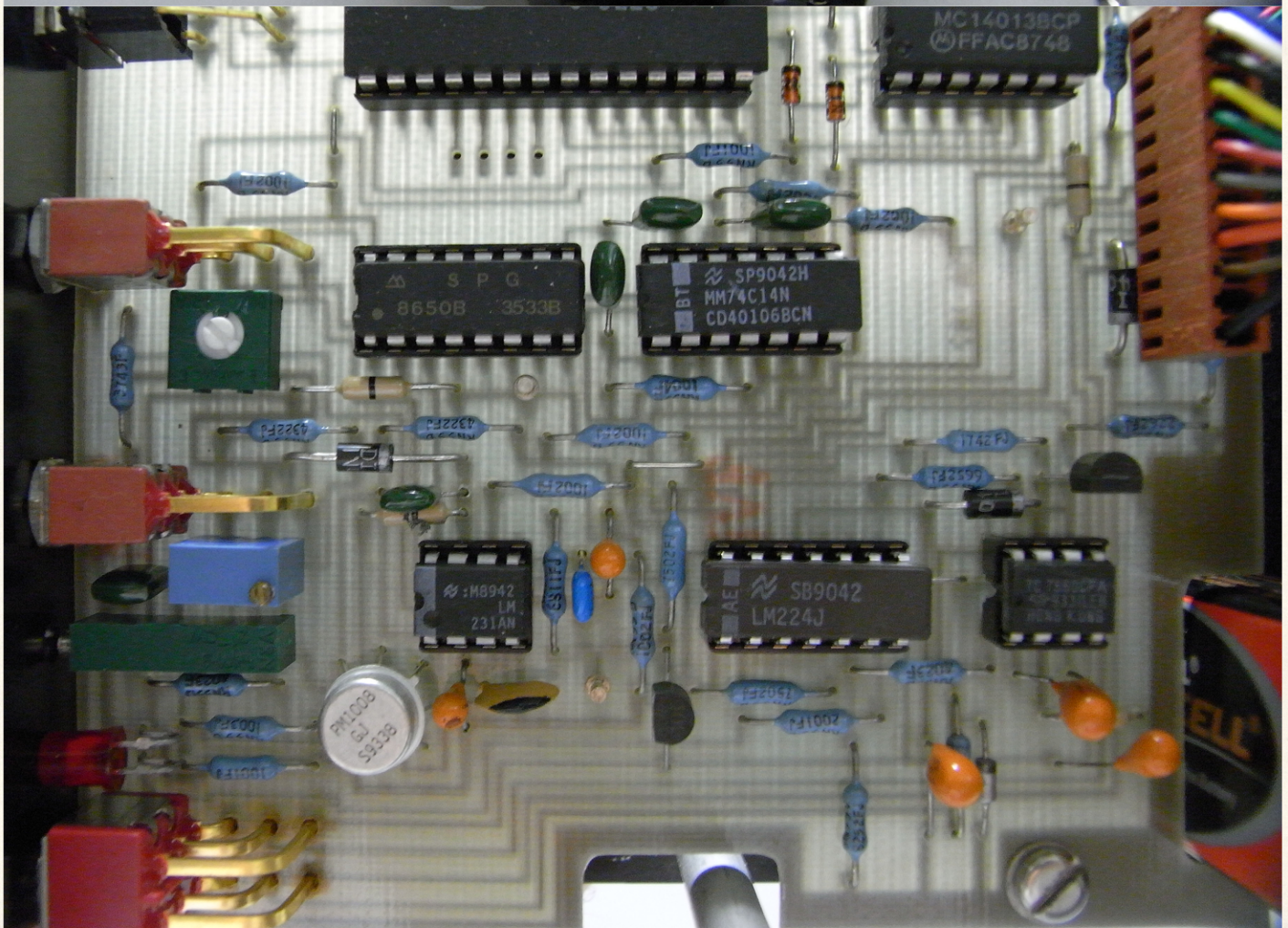
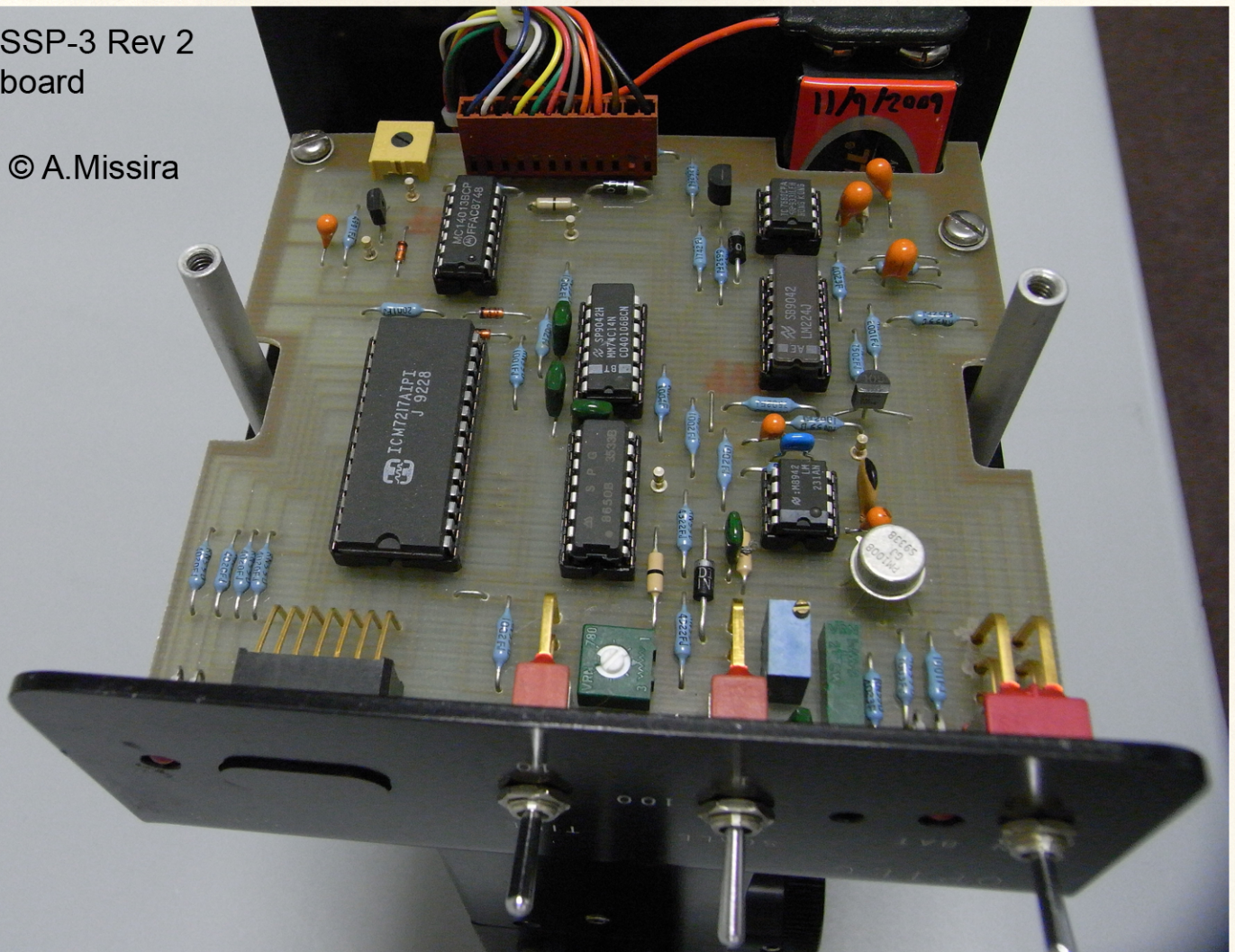


Revision 1
circuit board

Photos
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SSP-3 Rev 2
board

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APPENDIX A

ANALOG OUTPUT OPTION

Stock No. 17022

Field Aperture
Options

Electrometer
Output

Stellar Profile

Periodic Error

The analog output connector modification (stock no. 17022) adds a direct connection to the electrometer output. This modification includes a chassis-mounted 4-pin jack near the frequency output RCA jack. The 4-pin plug is included but may also be obtained from Radio Shack (part no. 274-001) and should be wired by the user to the chart recorder. The pin outs are given in Table A-1 below. The electrometer output is a 0 to -4.6 V DC signal with 50 msec rise time for the SSP-3. The SSP-5 is capable of rise times less than 2 msec. An inverting buffer amp is recommended since the connector is directly wired to the electrometer.

PIN NUMBER	FUNCTION
1	SIGNAL GROUND
2	SIGNAL, 0 TO -4.6 VOLTS DC
3	NOT CONNECTED
4	NOT CONNECTED
CASE	CHASIS GROUND, SHIELD

Table A-1. Pin Number and Function of Analog Output Connector.

Telescope Focal Length (Common Configurations)	Detector Aperture Size			
	0.3mm	0.75mm	1.0mm	2.0mm
1280 mm (8 inch f/6.3)	81"	121"	161"	321"
1600 mm (10 inch f/6.3)	64"	97"	129"	258"
2000 mm (17½ inch f/4.5)	52"	77"	103"	206"
2032 mm (8 inch f/10)	51"	76"	101"	203"
2540 mm (10 inch f/10)	41"	61"	81"	162"
2794 mm (11 inch f/10)	37"	55"	74"	148"
3912 mm (16 inch f/11)	25"	40"	53"	105"

Table B-1. Angular Size of Common Telescope/Aperture Combinations in Arc Seconds.

APPENDIX B

DETERMINATION OF FIELD APERTURE ANGULAR SIZE

Field Aperture Options

The SSP-3 and SSP-5 photometers offer a fixed aperture which must be selected at initial purchase. In most instances the standard field aperture of 1mm diameter is best suited. However, 0.5mm, 0.75mm and 2mm field apertures are also offered optionally.

Stellar Profile

To determine the angular size of each field aperture with a particular telescope, refer to Table B-1 below. Remember that even though the seeing disk of a star may appear as small as 2 arc seconds, the stellar profile may be many times larger. A good rule of thumb is to ensure the star's image remains within the central 70% of the field aperture to ensure that 99% of the stellar energy falls upon the detector. The reader is referred to section 9.4 of *Astronomical Photometry* by Henden & Kaitchuck (Optec stock no. 17330) for a full discussion of diaphragm selection and stellar profiles.

Periodic Error

Another important consideration in selecting an aperture size is the accuracy of the telescope mounting system. Periodic errors (as well as erratic errors) can cause the star to drift within the field. Your aperture must be large enough to ensure that the star remains within the center of the detector field of view for the duration of the photometer integration period, typically 10 to 60 seconds.

Telescope Focal Length (Common Configurations)	Detector Aperture Size			
	0.5mm	0.75mm	1.0mm	2.0mm
1280 mm (8 inch f/6.3)	81"	121"	161"	322"
1600 mm (10 inch f/6.3)	64"	97"	129"	258"
2000 mm (17½ inch f/4.5)	52"	77"	103"	206"
2032 mm (8 inch f/10)	51"	76"	101"	203"
2540 mm (10 inch f/10)	41"	61"	81"	162"
2794 mm (11 inch f/10)	37"	55"	74"	148"
3912 mm (14 inch f/11)	26"	40"	53"	105"

Table B-1. Angular Size of Common Telescope/Aperture Combinations in Arc Seconds.

